ESTIMATING RISKS OF BURNING IN MOUNTAIN LANDSCAPES: A GIS APPLICATION

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ABSTRACT

Ecological management of the Canadian Rocky Mountain National Parks involves the maintenance of fire adapted vegetation. This requires the use of planned prescribed burns in coniferous forests. Unlike many wildfires, prescribed burns are typically carried out during spring and fall seasons when the dryness of forest fuels is affected by topographic elements. With the knowledge that topography plays an important role in the probability of an area burning, this paper describes how to build *risk of burning* maps from two different methods using topographic elements and either stand origin data or modeling. These two maps were compared to determine how similar the modeling approach was to the map produced from stand origin information. It was shown that for mountain landscapes, it is possible to create acceptable *risk of burning* maps for regions with or without stand origin information. These maps are believed to be a useful tool to forest managers interested in maintaining historical patterns of wildfires through prescribed burning.

Keywords: fire risk, topography, Rocky Mountains

INTRODUCTION

Ecological management of the Canadian Rocky Mountain National Parks involves the maintenance of fire adapted vegetation. An effective tool for this is the use of planned prescribed burns in coniferous forests. Both wild and prescribed fires are affected by wind patterns which are influenced by the orientation of major and minor valleys to the prevailing wind; and by large barriers such as extensive ice, rock and alpine tundra which form the crest of various mountain ranges. As well, both types of burn are affected by the proximity of the Continental Divide, which influences the amount of summer rain and depth of winter snow pack, with amounts generally decreasing with increasing distance from the divide. Unlike many wildfires, planned prescribed fires are affected by topographic elements such as aspect and elevation, as these burns are typically carried out during spring and fall seasons when these topographic elements exert strong controls over the moisture content of forest fuels, limiting areas that be burned.

As part of a separate study, data from an extensive fire history study completed in Banff National Park and regions of Kananaskis Country (Figure 1), was used to determine to what extent terrain has influenced patterns of forest fires over the past several centuries (Rogeau, *et. al.*, In prep.). That research area encompassed 8000 km^2 of land on the east side of the Continental Divide, ninety percent of which is in the subalpine and alpine ecoregions. Rogeau, *et. al.* determined that forests which share similar combinations of topographic elements such as aspect, elevation, orientation of major and minor valleys and, proximity to the Continental Divide, have similar mean forest ages but these are significantly different from forest which have other combinations of these terrain. These elements synthesized many factors affecting the ignition and spread of fires in Banff National Park including wind patterns, precipitation patterns, variations in the rate of fuel drying (related to slope aspect to the sun and length of time areas are free of snow cover) and patterns of human and lightning ignition. That research also concluded that 80% of stand age patterns (from stand replacing fires) are explained by valley size and orientation to prevailing winds, elevation, aspect and proximity to the Continental Divide.

These topographic age patterns can be represented as *wildfire risk* or *probability of burning* maps, using either the stand origin data or, in similar landscapes using a GIS digital terrain model and weighing process for various elements previously identified as affecting fire frequency. The information from the *risk of burning* map can be used to duplicate frequency of planned prescribed fires to the pattern of historic fire frequency.

The objectives of this paper are to 1) describe how to build *risk of burning* maps from two different methods (data and modeling) and 2) compare the two maps produced to determine how similar they are when the stand origin information is known, but not used in the modeling approach.

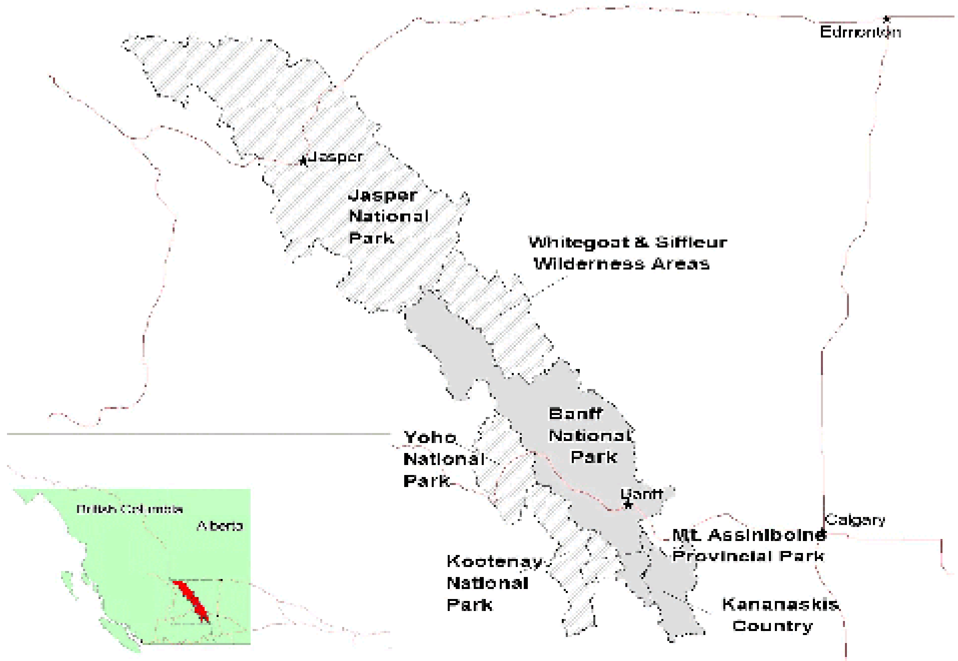

Figure 1. Fire history data from shaded area was used in the Topography Study, while the Whitegoat and Siffleur Wilderness Areas were chosen for building a *risk of burning* map from topographic elements.

METHODS

Risk of burning maps were created using two separate methods, both using GIS technology. The first method made use of the weighted mean age calculated for each combination of terrain elements, while the second map was developed using a weighing process to assign values to topographic variables according to their importance with regards to forest inflammability. The two risk maps were then compared for their similarity in order to determine if the weighing process method could be used for areas where no stand origin data is available. This process was done on a landscape believed to share similar precipitation and fire regimes as the landscape used in the Topography Study. As shown in Figure 1, the study area, namely the Whitegoat and Siffleur Wilderness Areas, is adjacent to the area where the effect of topography was tested and has a land base that is one fifth the size (1634 km^2). We felt that it was important to compare the two methods on a landscape other than the one used to study the effect of topography as those results were already being used to build criteria for the risk of burning map. The entire analysis is explained as a four step process.

STEP 1: Defining topographic classes

The first step of this process was to use a DEM at a 1:50,000 scale and a resolution of 100 m to classify *elevation* and *aspect* data into classes that were determined, as part of the Topography Study, to have a significant impact on risks of fire. *Valley orientation* and *distance to the Continental Divide* maps were also created and classified in a similar manner as for the Topography Study. The classification scheme is shown in Table 1. Valley orientation classes had to be modified to accommodate for the fact that some orientations of the Whitegoat/Siffleur Wilderness Areas did not exist in the Topography Study and vice-versa. In comparison to the Topography Study, the number of classes was overall reduced to ease and accelerate data manipulation. Note that the landscape was divided a priori into ecoregions as these are regulated by different fire regimes. This can be explained by the fact that ecoregions are characterized by different physical characteristics, human use patterns and precipitation regimes (Holland and Coen 1982, White 1985, Rogeau 1996).

Topographic variables	Ecoregions			
	Montane		Subalpine	
Valley orientation	1: M3 + S13* (5)		1: M3 (5)	
M: main valley, S: small valley	2: M4 + S14 (4)		2: M2-M4 (4)	
1: NW-SE orientation			3: S13-S21 (2)	
2: SW-NE “			4: S12-S14-S24-S34-S42 (1)	
3: N-S “		50%		35%
4: E-W “				
Divide	1: > 35 km (3)		1: < 35 km (2)	
	2: < 35 km (2)		2: > 35 km (3)	
		20%		20%
Aspect	1: SE-S-SW-W (5)		1: SW-W-S (5)	
	2: NE-E-FLAT (3)		2: NE-E-SE-FLAT (3)	
	3: NW-N (1)		3: NW-N (1)	
		30%		15%
Elevation	no effect		1: 1400-1500-1600 m (5)	
			2: 1700-1900 (4)	
			3: 1900-2100 (3)	
			4: > 2100 (2)	30%

Table 1. Number and composition of topographic classes used for Method 1 and 2. The number in brackets represents the weighing value while the percent value illustrates the importance of the topographic variable on risks of burning (Method 2).

* S13 is read as a Small NW-SE valley running perpendicular to a Main valley flowing in a N-S direction.

STEP 2: Method 1: Estimating risk of burning from topographic mean ages

This method consisted of calculating a weighted mean age (Johnson and Gutsell 1994) from an age-class distribution obtained from every combination of topographic elements. These combinations were composed of a *valley orientation* attribute, as well as an *elevation*, *aspect* and *distance to the Continental Divide* attribute. By analyzing the landscape in this manner, parcels of land sharing similar characteristics are likely to have a similar probability of burning, assuming that the probability of ignition stays constant through time (i.e. no changes in human use types or patterns). Over a long period of time and for a large enough study area, a constant probability of burning produces an age-class distribution of the negative exponential form. Under these conditions, the mean forest age becomes a surrogate to the fire cycle, and the inverse of the fire cycle is the fire frequency (Johnson and Van Wagner 1985, Johnson and Gutsell 1994). In this study, fire frequency was used to determine five classes of risk of burning ranging from 1) very low, 2) low, 3) moderate, 4) high to 5) very high.

STEP 3: Method 2: GIS weighing analysis

This method is a GIS ranking system that assigns a weight to topographic classes as well as to topographic variables with regard to their effect and importance on forest inflammability / risk of burning. The weighing values were arbitrarily determined based on the knowledge gained from the Topography Study. As an example, the most common and well known terrain effect on risk of burning is aspect. S-SW facing slopes have drier fuels due to longer sun exposure and will burn more frequently than north facing slopes (Zackrisson 1977, Tande 1979, Hawkes 1980).

As shown in Table 1, each class of each topographic variable was rated from a scale of 1 to 5, 5 being the highest risk of fire and, each map representing a topographic variable (*elevation*, *aspect*,...) was assigned a percentage weight according to the importance on its effect on risk of burning. The weight from all the maps must total 100%. Each topographic map was then multiplied by its weight and lastly, the four topographic maps were added together. The end result was a map of real data values ranging from around 0.5 to 5. Any regions with a value of 4.5 - 5 having the highest risk of burning.

STEP 4: Map comparisons

The *risk of burning* map created from Method 1, which made use of actual mean forest ages, also represent actual risks of burning over the landscape. In order to determine how well the weighing method predicted the risks of burning, the *risk of burning* map produced using Method 2 was simply subtracted from the one created in Method 1. The resulting map was a map showing regions with values ranging from 5 to -5, where zero values represented regions where the weighing process had perfectly estimated the risk of burning. These results were interpreted as follow: +1 values meant that the weighing method underestimated the risk of burning by one class, while -1 values indicated that Method 2 overestimated the risk by one class. Of course, the reliability of the weighing method would decrease rapidly should values approach ±5.

RESULTS AND DISCUSSION

As shown in Table 2, 31% of the pixels were well classified, while 5% underestimated and 55% overestimated the risk of burning by one class. We can see that in general the weighing process had a tendency to overestimate the risk and also that the risk of burning classification was not off by more than 2 classes. These results are encouraging, as 91% percent of the landscape had a risk of burning prediction that was accurate, or off by only one class. Further, the pixels that are not well classified will overestimate the risk of burning 93% of the time. This suggests that the risk of wildfire appears to be less than the risk of burning maps would indicate, and that the area should be treated with prescribed fire less often than the maps indicate.

Classification status	Area (ha)	% Area
Perfect	20,805	31
underestimated by one class	3,361	5
overestimated by one class	36,412	55
overestimated by two classes	6,286	9
Total	66,864	100

Table 2. Area and percent area of the weighing process *risk of burning* map that were perfectly classified or misclassified.

Table 3 shows exactly the flaws in the weighing process. The main valleys, all flowing through the montane ecoregion, and lowest elevations (also associated with the montane), were the main factors that contributed to a poor classification. Their rank values in terms of risk of burning were set too high for this region. Although, these topographic components are usually associated with higher risks of burning, the Siffleur/Whitegoat does not behave this way. A possible explanation is that due to lower levels of human use (both historically and currently) and possibly fewer lighting ignition occurrences, the probability of ignition in the Siffleur/Whitegoat is lower than for the Topography Study area. On the other hand, the weighing process

Topo. variable	Topo. classes	Perfect class.	Under by 1	Over by 1	Over by 2
Subalpine					
Valley Orientation	M3	10.0	0.0	80.2	9.8
	M4-M2	24.8	0.0	75.2	0.0
	S13-S21	72.4	26.7	0.9	0.0
	S12-S14-S24-S34-S42	50.6	10.1	39.3	0.0
Elevation	1400 - 1600 m	8.8	1.9	65.2	24.1
	1700 - 1900	36.7	4.1	59.2	0.0
	1900 - 2100	48.3	9.3	41.3	1.1
	> 2100	19.1	7.2	73.6	0.0
Divide	< 35 km away	32.4	2.8	63.2	1.5
	> 35 km away	41.6	12.4	44.1	1.9
Aspect	SW-W-S	26.8	5.2	65.9	2.1
	NE-E-SE-FLAT	51.8	7.4	40.0	0.8
	NW-N	20.5	4.8	72.1	2.5
Montane					
Valley Orientation	M3-S13	22.5	0.0	38.1	39.4
	M4-S14	12.7	4.9	59.1	23.3
Aspect	SE-S-SW-W	0.0	0.0	48.6	51.4
	NE-E-FLAT	0.0	0.0	72.5	27.5
	NW-N	98.9	1.1	0.0	0.0

Table 3. Risk of burning classification status shown as a percent area by topographic elements, for the subalpine and montane ecoregions.

worked best for the NW and N facing slopes of the montane ecoregion, where 99% of the pixels were perfectly classified. To improve the performance of the weighing process, it is suggested that a study of fire occurrence statistics, such as frequency, cause, seasonality and distribution, be undertaken a priori. This would help calibrate the fire risk ranking values for the landscape in question.

CONCLUSION

In mountain regions such as Banff National Park and the Whitegoat and Siffleur Wilderness Areas, terrain plays an important role in the probability of an area burning. This study showed that it is possible to create *risk of burning* maps from topographic elements. Such maps can be developed for similar landscapes with or without stand origin information, and the accuracy of the maps appears to improve for larger areas (> 4000 km^2). Differences in the frequency of human ignited fires may account for some of the variance not explained by the topographic model. However, the risk of burning maps are sufficiently accurate to be a useful tool for forest managers interested in maintaining the historic pattern of wildfires through planned prescribed fire.

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